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DRAINAGE OF AVOCADO ORCHARDS ON TERRACE AND UPLAND SOILS

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For the sake of desirable thermal conditions, avocados are commonly planted on terrace and upland soils. Most such soils are not rated high for general agricultural purposes because of the shallow nature of the topsoil, to which most r roots are restricted. Nevertheless, avocados often yield well in these soils.

The condition wherein trees lose vigor, and the foliage becomes sparse and pale, results from a rotting of the roots called melanorhiza by Horne.[3] Regardless of what causes this rotting, at least a temporary period of excessive soil moisture, with its accompanying poor aeration has hitherto always been observed.[4, 5, 6] The degree to which the tree is affected varies with the percentage of the roots subjected to this condition: trees may collapse within a few days, or may live on for years, showing only a few signs of decline.

Typical Condition on Steep Slopes

A typical condition during heavy rainfall or during an excessive irrigation is illustrated in figure 1. This is a profile of a primary soil,

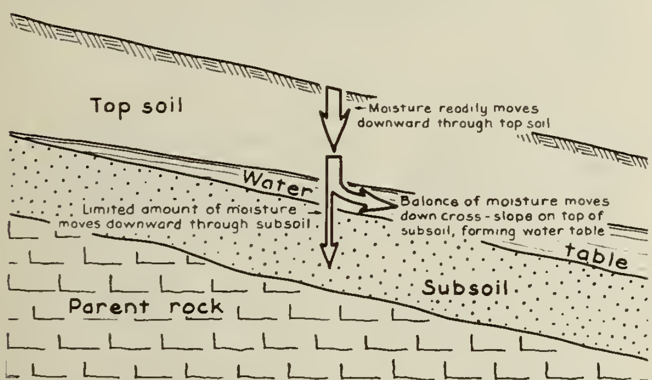

Fig. 1.--Profile of a primary soil on a steep slope, showing path of water movement in the soil.

a soil formed in place by the disintegration of the underlying parent rock. From 6 inches to 3 feet below the soil surface there is often a heavier layer with higher clay content. Rates at which water can move downward through the subsoil have been found to vary from about 1/3 to about 1/5500 of the rate it can move through the topsoil. Naturally, during heavy rains and sometimes during excessive irrigations, more water moves down through the topsoil than can move through the subsoil, the excess water flowing as a sheet down the cross slope on top of the subsoil. During this movement, more water is added, and the sheet or water table becomes thicker. More and more of the topsoil is accordingly saturated, with a resultant exclusion of air.

Upland soils do not always have less permeable subsoils. Sometimes the subsoil is no more impervious than the surface soil, but the underlying bedrock or substratum has weathered into material having a high clay content and is relatively impervious. Very often a hard but shattered bedrock is more permeable. Close inspection and testing are suggested to see whether or not there is a possibility of a water table's existing at any time.

Thus far the discussion has concerned primary soils. Old marine terraces, soils with dense claypan subsoils, border the uplands. A few avocado trees are planted on these soils and in older alluviums, which, too, have a heavier subsoil.

Conditions above the Water Table

In a freely drained soil that has been wet, the amount of moisture held after downward movement has practically ceased is called the field capacity of the soil. Moisture in excess of the field capacity may be used by plants, but in freely drained soils this condition exists only for a short time. From the field capacity to a certain minimum quantity that is characteristic of any soil, the moisture can be readily utilized by plant roots. Where a water table exists, the moisture content of the soil, especially within the first foot or two above the water table, remains above field capacity.

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[3]Horne, W. T. Avocado diseases in California. California Agr. Exp. Sta. Bul. 585:1-72. 1934.

[4]Huberty, M. R. "Overirrigation" of orchards. Pacific Rural Press 133:359. 1937.

[5]Wager, Vincent A. Phytophthora cinnamomi and wet soil in relation to the dying-back of avocado trees. Hilgardia 14:519-31. 1942.

[6]Huberty, Martin R., and Arthur F. Pillsbury. Solid, liquid, gaseous phase relationships of soils on which avocado trees have declined. Amer. Soc. Hort. Sci. Proc. 42:39-45. 1943.

Figure 2 represents the condition existing above the water table in a typical upland soil planted to avocados. In this chart the three phases of the soil--the water, the air, and the solids--are shown in their volume relations from

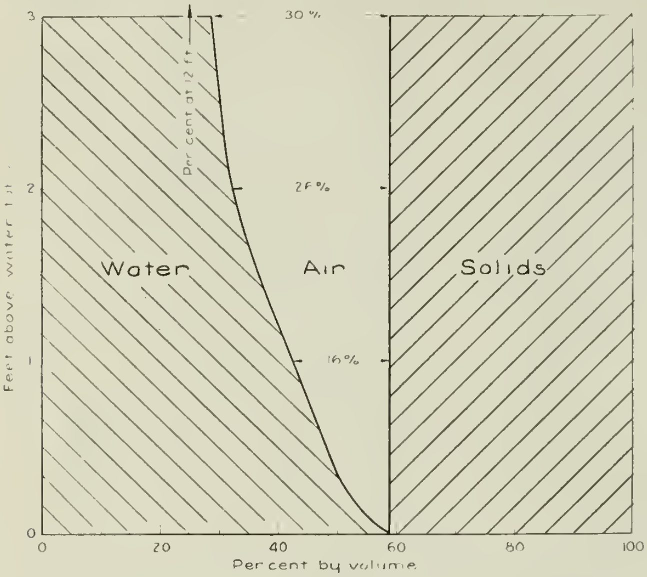

Fig. 2.--Water-air-solid relations by volume after downward movement ceases for the first 3 feet above a water table. Fallbrook fine sandy loam, topsoil.

the water table to a point 3 feet above. As long as the water table persists, no more water will drain away to permit a greater air volume. In this soil there is practically no air at the surface of the water table; there is 16 per cent air 1 foot above; 26 per cent 2 feet above; and 30 per cent 3 feet above. At field capacity there is 34 per cent air. This curve, of course, applies to this soil alone, and the upper part is theoretical only because the topsoil was actually but 14 inches deep.

The air present is emphasized because it appears probable that the soil environment favoring decline is associated with a lack of aeration (which accompanies excess soil water) more than with the water itself. Both time and the degree to which air is excluded may be important factors in creating this unhealthful environment. The water table is not permanent, but persists a few days to a few weeks after a heavy rain or an exceptionally heavy irrigation. Further, while water is still moving vertically through the soil less air will be present than is shown in figure 2. Although no single definite percentage of air can be said to be necessary for a proper environment, it is interesting to note how the air-water relations will vary with the kind of topsoil. This can best be illustrated by comparing the heights above the water table at which the soil contains 10 per cent air by volume. For the Fallbrook fine sandy loam in figure 2, the height is 5 inches. For other typical soils the following heights have been determined:

	Inches
Ramona loam	4
Placentia loam	4
Merriam fine sandy loam . .	8
Las Flores loamy fine sand.	11
A silty clay loam	23

In general the height above a water table where there is a given percentage of air is greater for fine-textured topsoils than for coarse-textured ones. Plantings on Merriam and Las Flores soils have generally not been successful. The Merriam topsoil is usually less than 12 inches in thickness, and the Las Flores topsoil is usually only 6 to 10 inches thick, so that the air in the soil, while a water table persists at the bottom, will be little indeed. The greater the height shown above, then, and the shallower the topsoil, the less chance there will be for success wherever there is a less permeable subsoil.

The value of artificial drainage lies in the fact that the water table will be removed more quickly after heavy rains or excessive irrigations and the table will not be so deep. This is true because the lateral flow is intercepted after traveling but a short distance. The longer the distance traveled, the longer the water table will remain and the deeper it will be. Increasing avocado decline with distance down the slope is commonly observed in the field.

Drainage is definitely not an assured remedy for decline but, if carefully used, may exert a very favorable influence on the delicate balance that exists in shallow soils between a healthful and an unhealthful environment. Many cultural practices, too, appear to be involved.

Soil Density

Another characteristic of soils should be discussed--namely, their density. For the soil shown in figure 2, less than half the volume is made up of solids. With compaction this proportion will be changed somewhat; the amount of voids--space occupied by air and water--will be decreased. As usually handled, the percentage of voids in topsoils should range from 40 to 60 per cent by volume.

To illustrate how the voids may be materially decreased--or, in other words, how the apparent density may be increased--consider the mixing of aggregate for concrete. To get a concrete of maximum density with, say, 1-inch maximum-size aggregate there should be just enough aggregate somewhat smaller (say 1/2 inch) to fill the larger voids; just enough (say 1/4 inch) to fill somewhat smaller voids; and so on down through sands to the finest dust. This dust is of greater importance in a uniform gradation of particle size for maximum density than is generally recognized.

The same relation between possible density and particle size distribution applies to soils as well as to concrete: density can be greatest

where there is a wide range of particle sizes from gravel down to the finest clay. Some soils are too deficient in clay to be capable, even with compaction, of high density. A clay soil is usually deficient in the coarser particles that are necessary for highest density. Mixing a loam with a dispersed clay, such as is commonly found in subsoils, usually results in a soil denser than either was before. The ability of water to drain from a soil depends upon the size and total volume of the pores, and these both decrease as density increases.

Ways of Minimizing the Need for Drainage

1. Deep, permeable, well-drained soils are to be desired.

2. Where the topsoil and subsoil vary appreciably in texture, avoid mixing them; indeed, avoid disturbing the subsoil at all if possible. (Increased density from mixing the soils is discussed in the preceding paragraph.) Referring again to figure 2: not only will the total voids be less, but the "wedge" of air shown above the water table will be considerably thinner.

3. Plant on a contour grade. Such grades most commonly range between 1 and 2 per cent (1 to 2 feet vertical drop in each 100 feet horizontal), depending on soil type, cross slope, and irrigation practices. Such a contour grade is essential for furrow or modified basin irrigation on steep slopes; it simplifies a more uniform application of water with sprinklers, affords the best possible control of surface runoff to prevent erosion, and facilitates any subsurface artificial drainage required.

4. Plant avocados on a mound or ridge to get them as high above the subsoil as practicable.

5. Avoid cultivation unless necessary for weed control. Even then it should be as shallow as possible. The avocado roots cut off in cultivation are those farthest from the water table, and so the most likely to be healthy. Oil spray is a possibility for weed control where cultivation is not practiced.

6. Use of organic matter on claypan soils or soils having dense subsoils can be questioned because it facilitates the infiltration of water into the soil, thus accentuating drainage difficulties, and may be involved in creation of the environment under which the roots rot. Counteracting these factors is the probable increase in rate of lateral drainage down the cross slope and the increase in the amount of air in the soil at a given distance above the water table, with increased organic content. (The air "wedge" shown in figure 2 would be widened.) Organic matter is an excellent soil conditioner, and some of the best orchards on soils where drainage might be expected to be critical have received repeated heavy applications of organic matter on the surface. So, although organic matter can increase infiltration, and can be a source of energy for root rot organisms, it is therefore believed that applications on the surface will, on the whole, be beneficial.

7. Under all circumstances, facilitate the removal of surface water. Keep contour-grade furrows or ditches open and clear throughout the winter, and provide for the disposal of the surface water down the cross slope. Do not allow water to pond in low spots.

How to Determine Ground-Water Conditions

Always obtain factual information on ground-water conditions in an orchard before proceeding with any drainage measures. The best procedure is to dig some short trenches in the area. After each heavy rain observe these carefully to see if moisture is seeping from the uphill side. Mark in the trench with stakes where this seepage takes place, and note the impeding layer below. If the topsoil readily seeps after prolonged rains it is coarse-textured enough for tile drains. Normally, the impeding layer will be the subsoil overlying bedrock, but instances have been found where it is merely a thin film of clay, an abrupt change in texture without any clay, or a plow sole. (All these latter impeding layers may have free drainage below and, if so, some treatment such as deep cultivation may be indicated.) If drainage is desired before the next winter, dig the trenches as outlined in the discussion on intercepting tile drains, and leave them open. Such open trenches will function satisfactorily as drains for one winter. Observe them after each heavy rain. Watch the uphill side to see if it seeps. See if the bottom is, at all points, at least 4 inches into the subsoil (below the zone which is seeping). To best observe this, scrape away the exposed face down which water is trickling. Also, you can observe the flow of water along the bottom of the trench to see that grade is continuous but not too steep. Then, in the following spring, make final adjustments of the system in the light of the above observations, and install the tile.

Need for Drainage of Trees Planted in Blasted Holes

In soils permeable below the subsoil, blasting of the subsoil, when thoroughly dry, has improved drainage. This relief may be only temporary. No relief at all can be expected in the soils more commonly planted to avocados because blasting compacts the subsoil and the material below the subsoil is usually impermeable. The blasted hole forms an almost perfect receptacle to hold water, and the water filling it may never drain away.

The most feasible method of alleviating this condition is to dig a trench on flat grade, extending downhill from the bottom of the blasted hole to the soil surface, or at least into topsoil. Then backfill with 3 or 4 inches depth of gravel or crushed rock. Complete the backfilling with topsoil. The grower should be cautioned that such a method can only be supplementary to other drainage measures.

In new plantings avoid blasted holes. In replanting, shift position of the tree and plant on a mound.

Surface Drains in Terraced Orchards

Where an orchard is terraced (fig. 3), the toe of the riser is usually at or near the subsoil. A small ditch or furrow at this point,

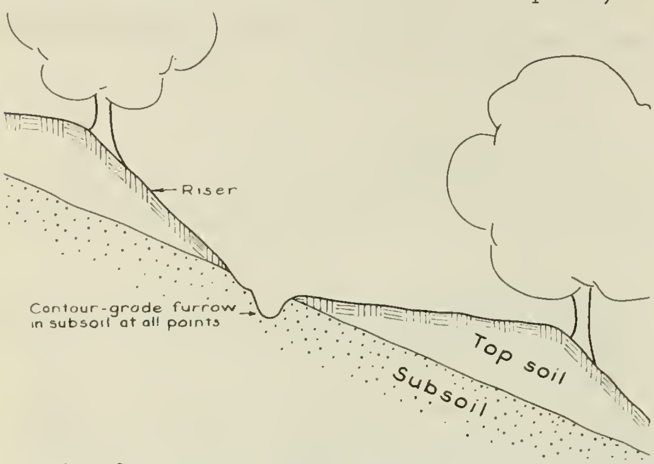

Fig. 3.--Cross section of a terraced orchard, showing positions of contour-grade ditches in the subsoil for drainage.

dug into the subsoil 4 or 5 inches, and kept clean through the winter, will intercept the water table and provide the best drainage. If the ditch is kept in the subsoil, the water flowing down the cross slope will all be intercepted and will not have an opportunity to reenter the topsoil on the downhill side of the ditch. Care must be exercised to avoid flat spots, especially at the ends of the runs, where the water often tends to pond. Such ditches may be longer than the usual furrow runs--continuing on across two or three such runs for 800 to 1,000 feet before provision is made for carrying the water down the cross slope.

As to terraces themselves, the use of preformed bench terraces is sometimes advantageous where the surface soil itself is heavy, and at least 3 or 4 feet deep. But with the more common soils of avocado plantings, in which the texture changes with depth, they should be avoided. Almost invariably there is a mixing of topsoil and subsoil, with an increase in apparent density. The practice of throwing up a small contour-grade ridge and planting on that ridge, however, is recommended. The resultant uphill furrow formed by the contouring can be used to carry the irrigation water for the first year. With such a program, the middles can be cultivated along the contour grade for at least two years, and a shallow terrace will develop. Such a terrace will facilitate orchard operations, besides making possible the contour-grade surface drains previously described. Later contour-grade cultivation of any appreciable depth will result in root cutting, in a tendency to work the subsoil into the surface soil, and in the tree trunks' being rather far down the riser. Shallow terraces should be formed, therefore, only when the trees are small, but when thus formed are certainly advantageous.

Installation of Intercepting Tile Drains

The purpose of intercepting tile drains is to cut across the path of the water sheet or table moving down the cross slope. All water from above will then flow into each lateral. Figure 4 shows a plan for a typical installation. Each lateral protects the trees below it, not those uphill from it. Tile drains function well in

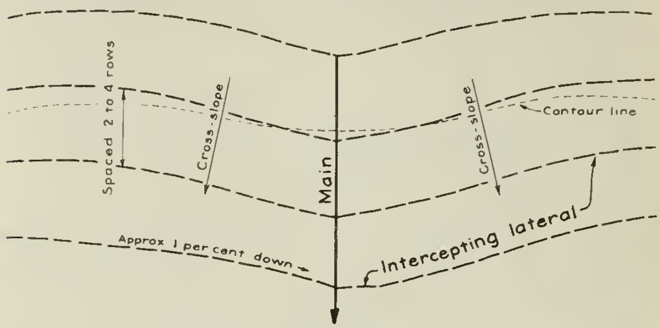

Fig. 4.--Plan of a typical tile drain system on a steep slope.

light to medium-textured topsoils, but will not function in very fine-textured topsoils. Check this before ordering tile, as previously suggested.

Four-inch tile is normally of adequate size for even the longest intercepting laterals. To intercept all water and to prevent any movement from the tile into the topsoil again, the tile must be below the subsoil level at all points. Dig the trench, therefore, at least 4 inches into the subsoil, and make it about 8 inches wide. Orchards planted on a contour grade are excellent for such tile drains because they are on a satisfactory grade of 1 to 2 per cent. More tile is necessary to drain a given area if laid on steeper grades. In addition, there is said to be some danger of steep lines' washing out, though this is not likely to occur where the installations have been carefully made. Flatter grades, 4 inches per 100 feet, and even much less, are satisfactory but are seldom required on steep slopes. In any case, considerable precision should be used in placing the tile and in checking grade at all points.

The best way to maintain satisfactory grade is to make the trench bottom smooth, and to check the grade every few feet with a grade board. A satisfactory grade board can be made by mounting a carpenter's level on the top side of a straight board (one, say, 1 × 3 inches or 2 × 2 inches) which is 8 feet long. Nail a block to the bottom of the downstream end of the board. Then, when the level bubble is centered, and the grade board is set on the trench bottom, the grade will be the correct minimum. The following tabulation shows the approximate thickness of the block to nail to the bottom of the downstream end of a board 8 feet long, to indicate the desired per cent grade:

Grade, per cent	Thickness of block, inches
0.5	1/2
1.0	1
1.5	1-1/2
2.0	2

As shown in figure 5, the tile is placed on the bottom of the trench. Then, to facilitate the movement of water into the tile, some gravel or crushed rock is placed along the sides and top, especially at the joints. Backfill the trench only with topsoil. Waste the subsoil which was excavated; or, in a noncultivated orchard, it can be used to form the ridge of a contour-grade ditch or furrow.

Unfortunately, in a high percentage of orchards where tile drains have been installed, the topsoil and subsoil have both been piled together and mixed up in excavating the trench. Refer to the section on soil density and you can understand that the resultant material available for backfill may not be very pervious. Not only will the drains be less effective because the water will not all move down to them, but the material may form a dike and tend to hold back the soil water draining down the cross slope.

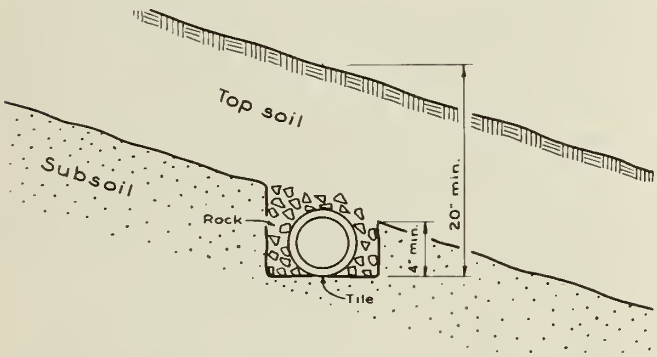

Fig. 5.--Cross section of typical tile drain installation, showing tile located in subsoil to insure intercepting all water and to prevent water from re-entering the topsoil on the downhill side.

In excavating, throw the topsoil uphill from the trench, and the subsoil downhill. If the trench has already been excavated and there is doubt as to the permeability of the material available for the backfill, use gravel to about 3 inches above the top of the subsoil at the sides of the trench.

Since grade must always be maintained and since the tile must always be below the top of the subsoil, tile must frequently be laid deeper in the subsoil than 4 inches because of varying depth to the subsoil. This situation is illustrated in figure 6. Digging deeply into the subsoil is hard, but can sometimes be avoided by a slight shift in alignment. Occasionally the line can be shifted up one tree row; but care should be maintained not to get too close to the trees.

As indicated in figure 6, some changes in grade are inevitable. It is not believed that short reaches in excess of 2 per cent present any hazard if kept to a minimum. But always

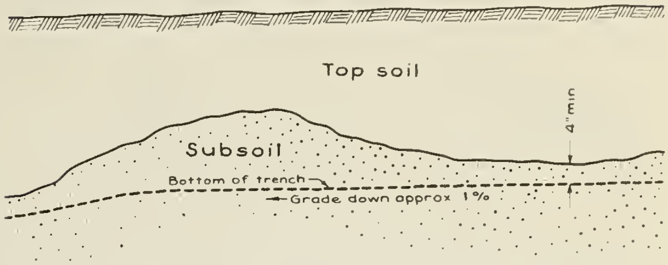

Fig. 6.--Profile along a trench line, showing how a cut must go deeper into the subsoil where the topsoil varies in depth.

remember that there may be less future inconvenience when uniform grade and good straight alignment are maintained as closely as feasible. Sometimes the lateral crosses an old fill where it is difficult to reach any subsoil. In such cases, seal the joints of the tile with mortar, and backfill the trench with thoroughly tamped moist clay to prevent any water from leaking out; omit the crushed rock or gravel.

Often the ends of the tile can discharge into a natural channel or into the lined ditch or pipe line for a surface drain system. Sometimes a main must be provided to carry the water down the cross slope (fig. 4). This main should normally be constructed with risers so that it also picks up surface runoff. It parallels the direction of ground-water flow, and so intercepts no water except from the laterals and risers themselves. It need not therefore be placed in the subsoil, but should have a minimum cover of 15 inches of soil over it. One must take precautions to prevent the main from being washed out by water moving down on the outside of the pipe. Concrete irrigation pipe, of ample size so that it will never run full, with tight mortared joints is preferred. Just downstream from each riser, place a bulkhead or wing wall clear around the pipe, and have it extend out about 2 feet on either side. This will cut off any flow along the outside of the pipe. Then leave an open joint at the bottom of each riser, and place gravel around this open joint. The wing wall, if made of concrete, should be about 4 inches thick. A method generally just as satisfactory is to tamp in thoroughly a core wall of moist clay excavated from the subsoil of the laterals. Any surplus of subsoil from the laterals can well be tamped in around and over the main along most of its length.

The main should be designed so that it will not run full with a maximum of about 1 cubic foot per second per acre runoff from subsurface plus surface drains.

Wherever there are open ends of a drain line, cover them with about a 1/4-inch-mesh hardware cloth to keep small animals out.

Costs and Quantities for Drain Tile

Spacing: Field data adequate to justify definite recommendations for the spacing of laterals are not yet available. Apparently one lateral every four tree rows (80 to 120 feet) may be adequate in some cases; but closer spacing will, as a rule, probably be necessary. It is well, therefore, to install tile with two- to four-row spacing and, if these are inadequate, to install intermediate lines at a later date. A progressively decreasing beneficial effect on the trees below each lateral would indicate that closer spacing is desirable.

Rock: It is tentatively suggested that 1 cubic yard for about each 75 feet of intercepting lateral be used. More will be needed if there is any question as to the permeable nature of the material available for backfill of the trench. Any gravel or crushed rock, from which all material finer than coarse sand is excluded, will be satisfactory. Cost may run $2.50 to $3.00 per yard delivered. If costs are the same, crushed rock is preferred to gravel, and a coarser material is better than a finer material.

Tile: Either vitrified clay tile or good-quality concrete is satisfactory. Delivered cost has been about 5-1/2 cents per lineal foot in San Diego County.

Cost of materials for laterals can therefore be estimated at 10 cents per lineal foot. If a main is required, cost of materials for that may run about $10.00 per acre. Cost of a fully completed system is usually two to three times the cost of materials alone.

Deep Soil Pockets with Undersurface Dikes

Under certain conditions a water table has been, at least temporarily, built up in deep topsoil because of the obstruction offered by an undersurface dike somewhat down the slope. The solution is to place a drain line through the dike, or around the dike, to prevent the basin above the dike from filling with water.

Drainage of Plantings on Flat Hill Tops or on Flat Benches

Methods of drainage so far discussed are designed for sloping land. Drainage problems may exist with similar soils on flat hilltops and flat benches. Here, construct a gridiron system of ditches along the middles as shown in figure 7. The ditches go both ways--that is, north and south and east and west--in each middle. This arrangement permits rapid surface drainage and a rapid removal of any sheet of water on top of the subsoil. Because of erosion hazards, the system should not be used where cross slopes exceed 3 per cent (or somewhat less if cultivation is practiced). Keep ditches clear in winter.

Under such conditions of soil and slope, orchards have few commercial possibilities. The method does, however, permit saving a few trees in flat spots, especially in home orchards.

Effect of Irrigation

Excessively heavy irrigations can and do accentuate decline, but experience indicates that most drainage problems arise in winter and spring from heavy storms rather than in summer from irrigation. Roots damaged in winter may, however, not affect the trees until summer, because trees need a smaller number of roots when transpiration is low. In summer, when transpiration is high, the declining tree will suffer from a lack of water because the few healthy roots can supply only limited amounts. Thus trees suffering from too much water in winter are more liable to suffer from a lack of water in summer, and so should receive more frequent but lighter irrigations than healthy trees.

Irrigation applications should be carefully controlled. Control can be facilitated by irrigating only a portion of the soil under each tree and irrigating the balance of the soil midway of each regular irrigation interval. Thus, actual interval and total application are not affected, and moisture is always readily available. Any practice that may prevent moisture from being always readily available is not advised.

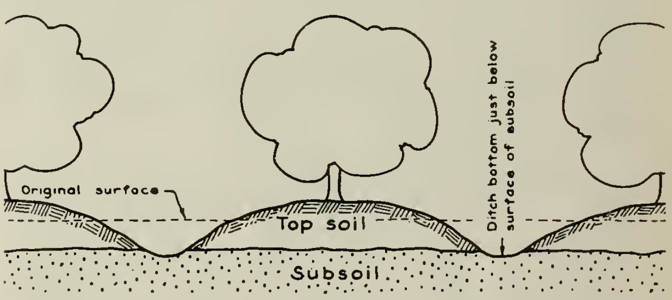

Fig. 7.--Cross section of an orchard, showing the gridiron system of ditches recommended where cross slopes do not exceed about 3 per cent.

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